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Reconstruction of the isotope separator at the Nobel Institute of Physics

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With 15 figures in the text

ABSTRACT

At the Nobel Institute an electromagnetic isotope separator has been working since 1948. Applications of this have been separations of radioactive material used in nuclear spectroscopy and preparation of targets of stable isotopes for nuclear reaction studies. However, such work in the lead region emphasized the importance of better resolution, which was found to be attainable by using the analysing magnet as a symmetrical sector field. To fulfil the new requirements, an extensive reconstruction of the isotope separator has been made, including a new vacuum system and lens system. Further, the instrument has been made two directional focusing by an electrostatic cylinder lens, with which it is possible to diminish the line height by a factor of 5, or to 10 mm, without any appreciable defocusing. To analyse the focusing properties a partly new method has been developed which makes it possible to make continuous observation of the mass lines during the separation. The resolving power obtained is about 1400; the overall efficiency corresponding to this value is a few percent.

Introduction

One class of electromagnetic mass separators which has found application in nuclear physics research is the "low intensity isotope separator". Such an instrument is characterised by having a resolving power of the same order as is used in mass-spectrometry. However, as the main domain of application is separation of radioactive material, and μg quantities of stable isotopes, the efficiency and the ion current must be much higher than in a masspectrometer. This is in principle achieved by using more efficient ion sources and omitting all kind of stops. Well defined ion beam is instead obtained by using only a focusing system and larger accelerating voltage. This cannot, however, reduce the "tails" of the mass lines as completely as is done in a mass spectrometer. In this way it is possible to obtain an efficiency of about 10 % for gases with relatively high resolution. The ion current used is usually of the order of 10 μA, enough to get an easily observed reference line.

An apparatus of this type has been in use for some years at this institute [1, 2, 3]. The analysing magnet forms a 90° homogenous field with an ion path radius of about 160 cm. In the original performance, the ion optics was arranged in the following way. Ions were drawn out of the ion source through a small circular hole by an

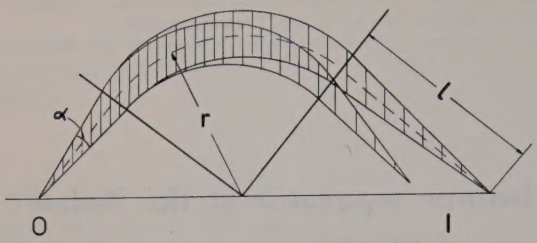

Fig. 1. The magnetic focusing.

electrode system. This focused and accelerated the ions to about 50 kV so that these formed a parallel beam at the entrance of the magnetic field. After a deflection of 90°, the ions were collected at the edge of the magnet. The defocusing of the ion beam by gas scattering and coulomb repulsion effects was thus reduced to a minimum.

However, by experiment with different focusing conditions, Thulin [3] reached a similar conclusion as earlier Koch [4], that the resolving power is increased if the magnet is used as a symmetrical sector field. The collector is then situated at a distance equal to the radius of the ion path in the magnet from the edge of the magnet. The reconstruction of the isotope separator described in the following has consisted partly of refinements necessary to accomodate this larger resolution and partly of a reequip of the instrument as a whole.

General remarks of focusing conditions and requirements of the reconstruction

The wellknown focusing condition in vacuum for charged particles in a homogeneous magnetic field (cf. e.g. 5) is shown in Fig. 1. It is drawn for the special case actual here with a 90° sector field and normal entrance of the beam. For further discussion on focusing it is suitable to introduce an x–y coordinate system in which the axes are perpendicular to the trajectory of the ions and where the x-axis lie in the same plane as the cross section in Fig. 1.

As the field acts as a cylindrical lens, there is no focusing in the y-direction, which results in mass lines at I. This is usually not a drawback if the only purpose is to separate isotopes, but it is a disadvantage when one also wants direct preparation of beta spectrometer sources and targets. As these usually must have smaller extension in the y-direction than the mass lines have a loss of separated material cannot be avoided unless an auxiliary focusing system, which compresses the lines in the y-direction is used. For further discussion of this we define here the line height of a mass line as the height at the half width of the y-intensity distribution.

Even in the x-axis the mass lines have sometimes too large an extension which makes it impossible without further to use the method of direct preparation. In these cases one had to use some kind of stops in front of the collector, which transmit only a part of the beam. The different factors giving the intensity distribution on the x-axis has been discussed in some detail elsewhere [3, 4, 6]. In our case the most important contribution to the line shape arises probably from the energy spread of the ions, aberrations of the lens system, residual gas scattering and space-charge effects. Also fluctuations in the high tension and magnetic field will contribute. However, these can be reduced considerably by using a beam stabilizer as described later. Aberrations from the magnetic field plays no important role due to the small size of the diverging beam angle α (which is of the order of 0.5°).

To be able to discuss more easily the resolving power $P = M/\Delta M$ of the instrument, it is suitable to define this for instance from the half width (B) of the intensity distribution of the mass lines. It is possible to express P explicitly in geometrical quantities and the half width by introducing the mass dispersion (D). For the case in Fig. 1 this can be written as (cf. e.g. 5).

$$D = \tfrac{1}{2}\frac{\Delta M}{M}\{r + l(1 + \operatorname{tg}\varepsilon)\} \tag{1}$$

where M = mass of the ions
r = radius of the ion path
l = distance of the image from the exit boundary of the magnet
ε = angle between the beam and the normal to the exit boundary of the magnet.

For the resolving power one thus finds, if one neglects ε

$$P = \frac{1}{2B}(r + l). \tag{2}$$

As mentioned above, the resolving power was increased when the magnet was used as a symmetrical sector field. When l is increased from 0 to r the dispersion is increased by a factor of two (if $\varepsilon = 0$). Empirically [3] it was found by this procedure that the line width remained approximately constant or decreased slightly. The resolution was therefore increased by the same amount. The fact that the line width was not increased when the ion path was made larger was probably due to the spherical aberration of the electrostatic lens system being simultaneously decreased. This compensated for other effects that should increased the line width.

In the original construction of the apparatus, a resolving power of about 300 could be reached. This is usually sufficient for low and medium masses. To separate isotopes with higher masses sufficiently pure for nuclear spectroscopy work it is, however, often necessary to have better resolution. This could be obtained by the method described above. However, for a complete utilization of this better focusing condition, a large reconstruction of the isotope separator and its equipments had to be done. The most important changes were as follows.

1. An external extension at the collector side and a new acceleration chamber.
2. Increased pumping effect.
3. Freon cooled baffles to decrease pumping oil film on the targets.
4. A system focusing the lines in the y-direction.
5. Movable accelerating system.
6. An ion source especially for solid substances.
7. Improved fine stabilization system.
8. A new technique for detail detection of the mass lines.

In the next sections a description of some details of the rebuilding are given. For completeness a few older arrangements will also be discussed.

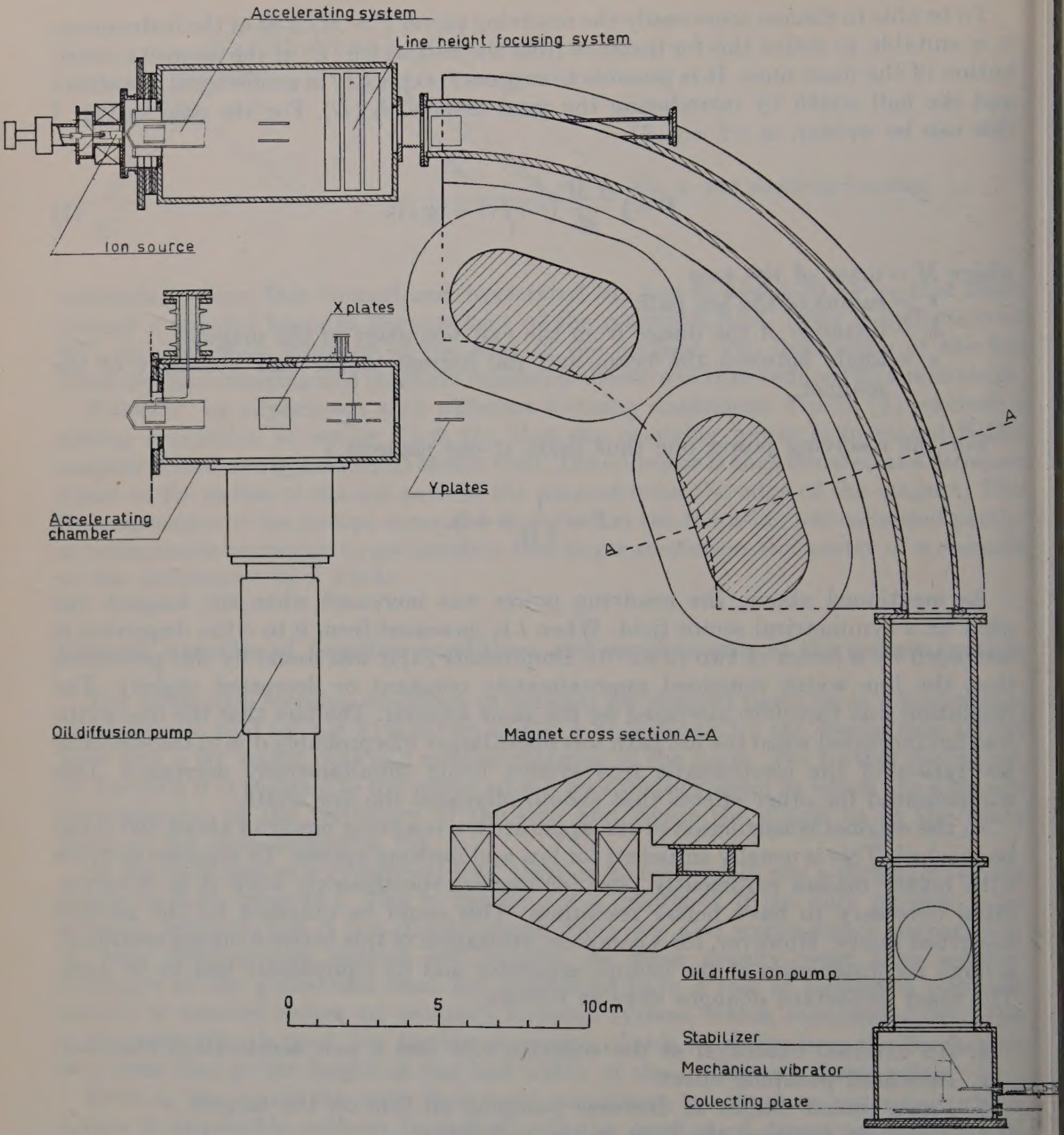

Fig. 2. Cross-section of the isotope separator.

The vacuum system

Almost the whole vacuum system has been newly constructed. On the ion-source side, a more spacious vacuum tank has been installed. This was necessary in order to make room for the new ion-optics arrangements. The tank is of iron to prevent any stray field from the magnet from penetrating into the lens system and there causing sparks between the electrodes. Measurements of the field inside the tank

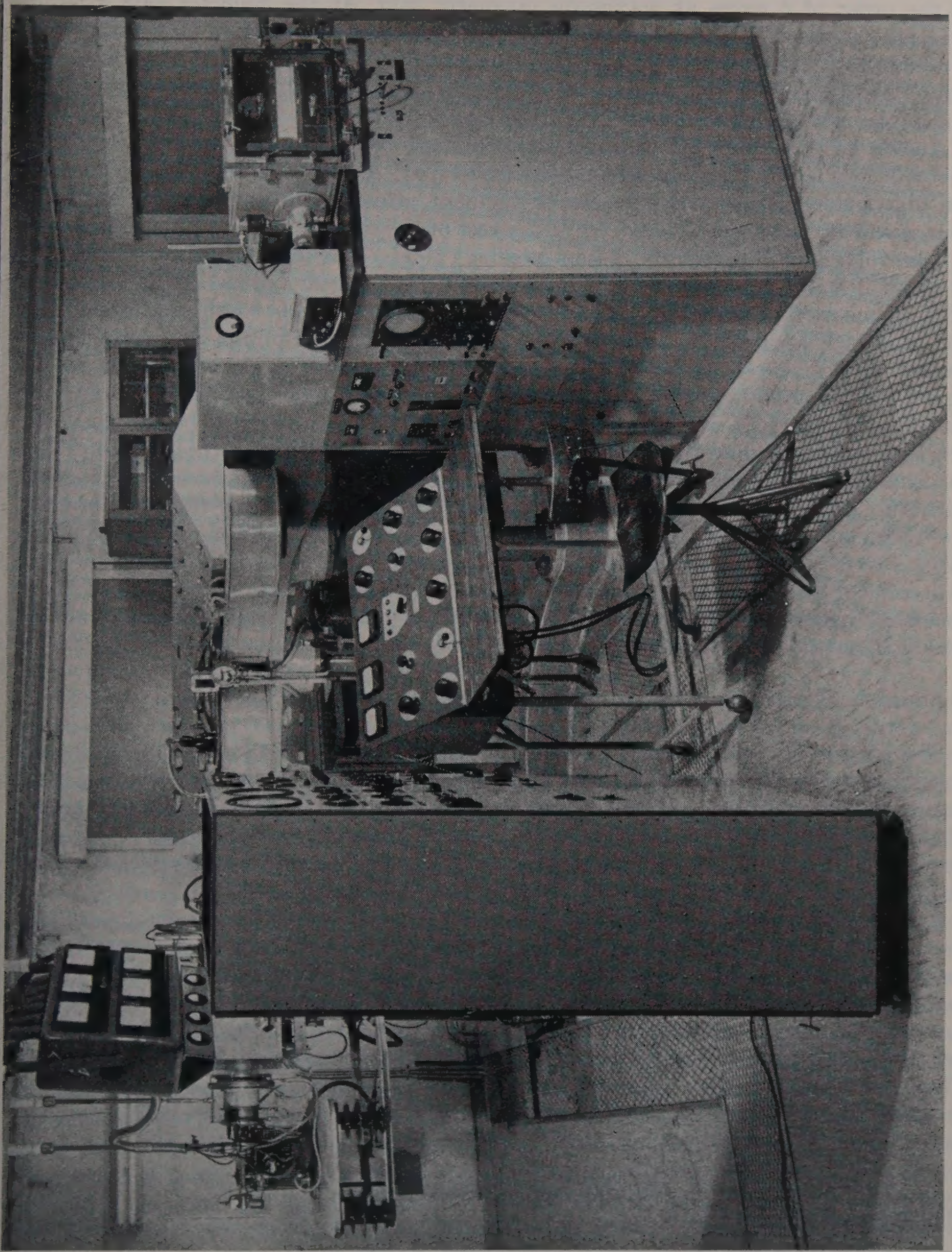

Fig. 3. View of the separator. The collector arrangement is at the right.

have shown that the shielding is nearly complete. The field in the middle of the tank is of the order of 5 gauss at maximum magnetic field. At the collector side a large external extension is built which make it possible to collect a relative mass difference of about 15 % simultaneously. This was the capacity of the older arrangement with target at the edge of the magnet. Further, the target chamber is built spatious to house the new detection devices (see Fig. 11).

A slide valve is mounted near the collector tank so that it is possible to work at the collector without letting air into the other part of the vacuum system. On the ion-source side there is also a valve arrangement, which permits changes in the ion-source and with the lens system, while the rest of the system remains under vacuum.

The volume of the vacuum system is about 300 l. It is maintained at a pressure of about 3×10^{-6} mm Hg under running conditions by means of two RLN diffusion pumps, one at the ion source side, of capacity 1400 l/s at 10^{-4} mm, and a smaller one at the collector side of capacity 500 l/s at 10^{-4} mm. The pumps have now freon cooled baffles. These are hold at a temperature of about −35°C by an $^1/_3$ hk freon aggregate. The main reason for using freon cooling is an attempt to avoid pump oil on separated targets, which sometimes causes trouble. A particle beam from an accelerator bombarding such targets looses energy by penetrating this oilfilm. This can therefore sometimes frustrate precision work. The energy loss has been studied with the Cockcroft-Walton accelerator at this institute by a (d,d) reaction on two Ne^{20}-targets, which have been separated with and without freon cooling resp. The targets were separated to saturation in both cases. With a primary energy of the deuterons of 800 keV, the energy loss in the two cases was 0.5 and 2.5 keV resp. To get specially carbon pure targets, however, it is still necessary to use a liquid air cooled trap just behind the collector.

The ion source

The ion source used originally was of the low voltage arc magnetic type and was constructed only for investigation of gases [1]. To be able to handle also solid material an ion source which was specially built for this purpose has been installed. This is of the oscillating electron type and is a construction made by the isotope separator group at U.I.T.F. [7], (Copenhagen). Below a few remarks of its characteristics will be given.

The ion source is furnished with an oven, which can be heated up to about 1000°C. As in many cases it is necessary to separate short lived activities, the furnace is so mounted that it may be removed for loading through a valve without breaking the main vacuum. The time necessary for this procedure is rather short, which enables a separation to start already a few minutes after charging the furnace. In order to get stable discharge in the ion source, a few mg of charge material is usually needed. Thus, for instance, when the starting material is of high specific activity, carrier must be added. This is of course also necessary in order to get observable reference lines.

The ion optics arrangements

The lens system

Since the magnet is used as a symmetrical sector field, the object and image had to be at equal distance r from the edge of the magnet. The object formed between the outlet of the ion source and the extraction electrode is, however, situated at a

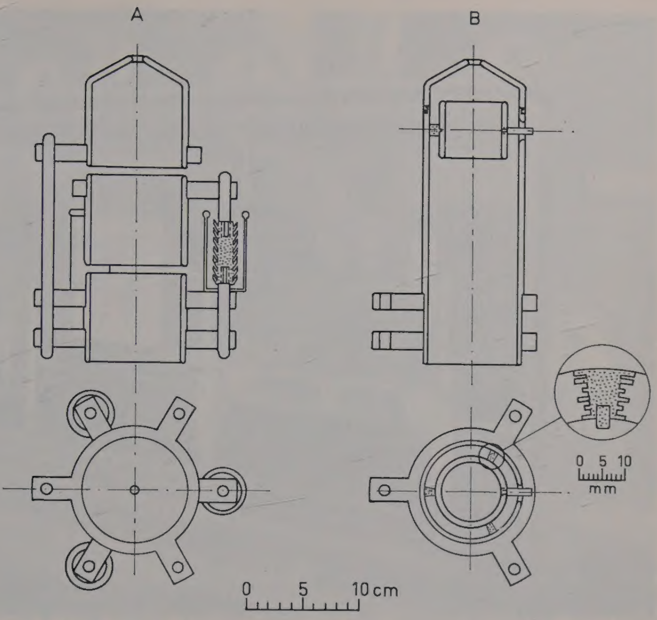

Fig. 4. Two different methods for suspension of the electrodes of the accelerating lens system, which have been investigated. Type B is that now in use.

distance smaller than 1.6 m from the magnet in order to diminish the size of the acceleration chamber. It is therefore necessary to have a lens system giving the right position of the object.

The lens system now in use consists in principle of three cylindrical aluminium electrodes, the extraction electrode on earth potential followed by an electrode on focusing voltage and an earthed one. As different separations have different requirements of focusing and efficiency, it must be possible to change these easily. In the three electrode case one has to vary the distance between the outlet of the ion source and the extraction electrode (*d*) in order to reach this possibility. For example by diminishing this distance, the ion current is increased and therefore also the efficiency of the instrument. However, by this procedure the opening angle of the beam through the extraction electrode is increased. This together with the larger current causes larger aberration in the lens system and therefore decreases the resolving power. To be able to easily adjust these during operation, it is necessary to move either the ion source or the lens system. In the last case the electrodes must be built together into one unit instead of each being suspended separately as is mostly used. As the lens system in this case should also have a better mechanical stability and all problems of centering of the electrodes should be solved, this way has been tried.

A suspension of electrodes sometimes found in electron optics is shown in Fig. 4, type A, as applied to our case. The difficulties with the system discussed here is the insulation of a much higher voltage (30–50 kV), than used in the electron case. With special machined plexiglas insulators—well screened from ions and secondary electrons—between the electrodes, it was possible to realize this method. However, another system, which has been found much more simple to construct and handle is that shown in Fig. 4, type B. The electrodes are here in principle suspended in a larger cylindrical tube. The focusing electrode is fixed and insulated from the tube

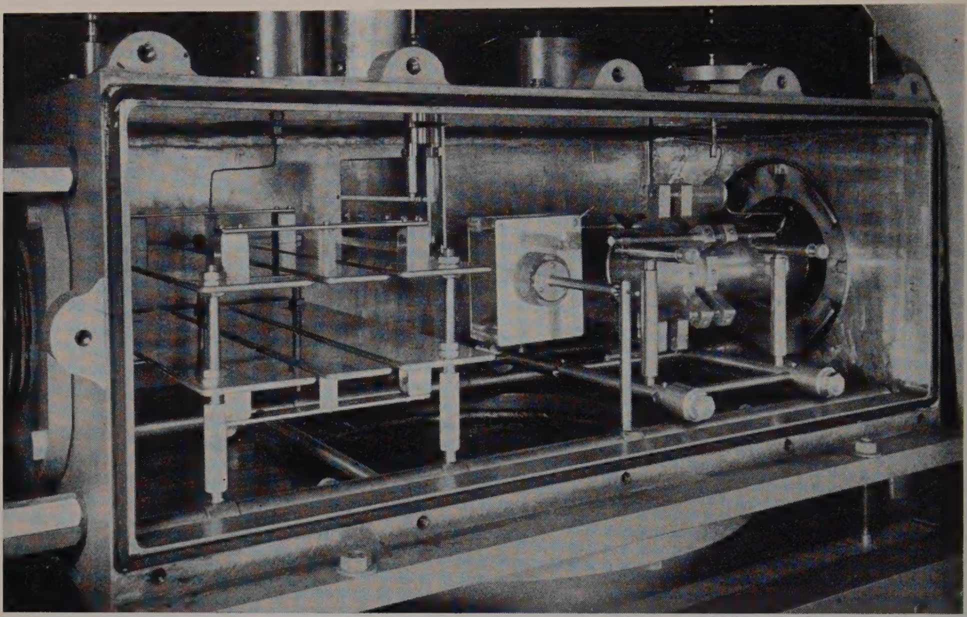

Fig. 5. The electrostatic arrangements in the acceleration chamber. From left the cylinder lens, a shutter with adjustable aperture, the stabilizer plates and the accelerating system.

by three small, specially formed plexiglas insulators, which by this suspension method are well screened from ions and secondary electrons. In the case shown in Fig. 4 type B the outer tube is also used as the earth electrodes.

The whole lens system is suspended in a carriage, which can be moved along two bars and be regulated from outside. Fig. 5 gives some idea of the construction. The figure shows also the other ion optics arrangements, which will be described below.

Lastly it should be mentioned that in the orginal performance of the separator a fourth electrode was inserted between the ion source and the first earthed electrode at a potential of the order of 10 kV below that of the ion source. This second focusing electrode means variable magnification and thus the possibility of decreasing the ion density in the beam. However, this is of less importance with ion currents of the order of 10 μA. Further there was often a need to change the distance between the ion source and the lens system even in this case. This shows that a movable three-electrode system is sufficient for our purpose.

Line height focusing system

At a typical value of the distance between the ion source and the first electrode of 50 mm corresponding to a resolving power of about 1000, the ion beam from the lens system diverges with an angle of about 0.5°. This gives a line height at the collector of approximately 40 mm. As mentioned earlier, in order not to loose material when preparing betaspectrometer sources and targets, it is necessary to use an arrangement focusing the beam along the y-axis. The ideal case is, of course, to be

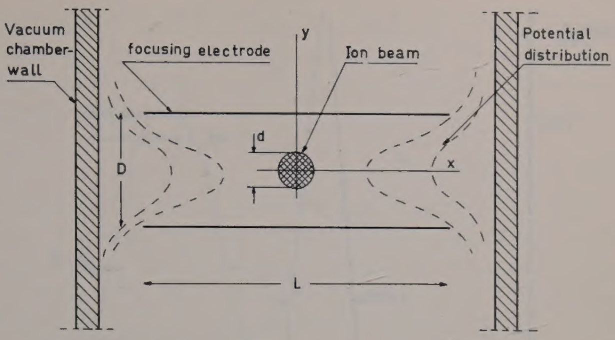

Fig. 6. A cross-section through the middle electrode of the cylinder lens perpendicular to the beam, indicating the potential distribution between the vacuum chamber walls and the middle electrode.

able to get "point focusing", but often when separating sources for prismatic spectrometers for example a line height of 10–15 mm is acceptable.

Three simple focusing systems have been investigated as described below. To be able to use these arrangements only small defocusing effects of the mass lines could be tolerated in order to retain the improved resolution. For testing the focusing, measurements have been done both with radioactive and stable isotopes. The radioactive isotope used has been Kr^{85}, which has been collected on Al-foils for a few minutes. The line shape of the normal and compressed lines has then been measured with help of a 0.2 mm slit in a GM tube. In the case of the stable isotopes, the lines have been recorded by the oscillating probe described later.

A focusing on the y-axis can be obtained by rebuilding the magnet from a homogeneous field to a double focusing field. Such a procedure was, however, assumed to be too time-consuming. Another method using magnetic field has, however, been tried. By oblique exit of the beam from the magnet, one can obtain a focusing in the y-direction as described for example by Herzog [8]. Preliminary measurements with such an arrangement showed that a desired compression of the lines was obtained. The degree of focusing followed the calculated value one should have for a system with a focal distance $f = r/\mathrm{tg}\,\varepsilon$ where ε is the angle between the beam and the normal to the edge of the magnetic field. However, defocusing effects could not be avoided. For instance, at a value of $\varepsilon = 45°$, a decrease of the resolving power by about 50 % was found. That this does not depend on the increased ion density in the beam is shown by the method now in use described later on. Owing to these facts the system was abandoned.

As the ions are accelerated only to about 50 keV, it is possible to use electrostatic focusing systems. These have the advantage over the magnetic arrangements in that they easily grant a variable line height, which is suitable in our case as different sizes of the separated sources are usually required. Two such systems have been investigated in more detail, the first of these being the electrostatic cylinder lens. This has in fact also been found to be the most satisfactory one. The cylinder lens is built up in the same way as the accelerating system, but the electrodes here are plane plates. In order to focus all mass lines simultaneously the system must be situated at the entrance of the magnetic field, which also is the case for all experimental set up discussed below.

Possible defocusing in the x-axis on the beam, when it passes such a cylinder lens, is due to two different effects. Firstly, the field distribution between the vacuum chamber walls and the middle electrode cause a broadening of the beam (see Fig. 6).

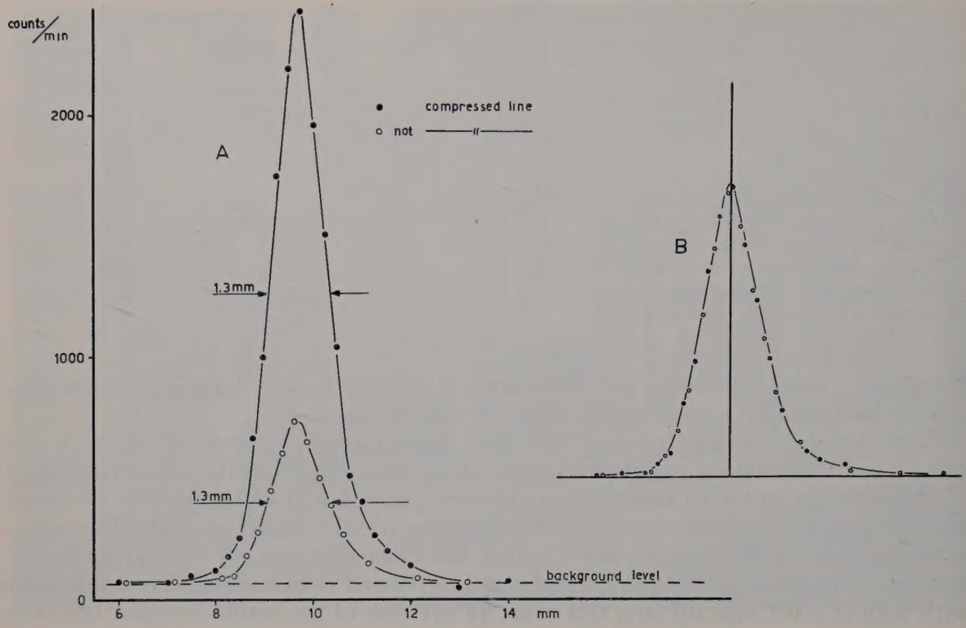

Fig. 7. Focusing properties of the cylinder lens. *A* shows the intensity distribution of Kr^{85} in the x-axis with and without use of the cylinder lens. The line shape is measured with help of a slit having the dimensions 0.2 × 10 mm. *B* gives the same two line shapes but these are here normalized to have the same top peak intensity.

Secondly, coulomb repulsion is increased, when the beam is compressed, thus also giving a contribution to the defocusing. To distinguish between the two effects, measurements on the compressed and normal lines at the collector can be made with the radioactive isotope Kr^{85} which correspond to "zero currents" (the Kr^{85} current is of the order of 10^{-11} A) in conjunction with stable isotopes corresponding to ion currents of about 10^{-5} A. As the cylinder lens is situated just at the entrance of the magnet, the isotopes are nearly separated along the whole distance between the cylinder lens and the collector. Possible broadening of the Kr^{85}-line gives therefore approximately the defocusing due to the first effect. Coulomb repulsion can then be estimated from broadening of the stable isotopes. In this way it has been proved that the defocusing due to the last effect is very small; an increase of the line width of about 10 % has been observed. Thus the coulomb repulsion effect is negligible at the actual currents.

Line defocusing due to the first effect, however, could not be neglected without further. Several cylinder-lens systems were investigated with special regard to the dimensions of L, the length of the electrodes in the direction perpendicular to the ion beam and of D, the distance between the two plates in the electrodes (see Fig. 6). It was thereby obvious that the ratio L/D had to be large. That the focusing is very senstitive for small durchgriff can also be seen from the following rather rough calculation, which gives the influence of an electric field in the x-direction.

The deviation (Δb) an ion gets when passing a deflector of length a is

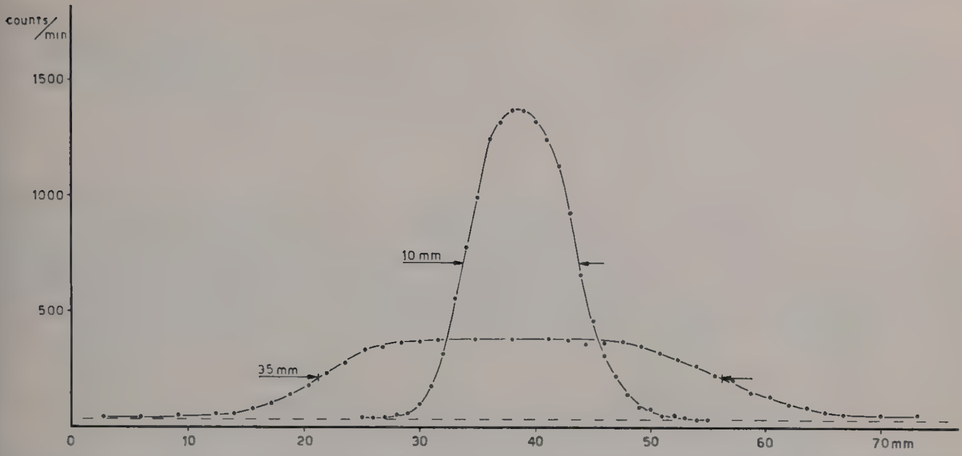

Fig. 8. Focusing properties of the cylinder lens. The two lines of Kr^{85} in Fig. 7 are here measured in the y-axis. The line height is decreased a factor of 3.5 by use of the cylinder lens.

$$\Delta b = \frac{a\,S}{2\,V_0} \operatorname{grad} V \qquad (3)$$

if S is the distance between the deflector and the point where Δb is observed, V_0 the voltage corresponding to the velocity of the ion and V the potential in the deflector. By using this expression on an ion, which pass the cylinder lens it is possible to get an estimation of $\operatorname{grad}_x V$. V_0 and $\operatorname{grad}_x V$ will of course be some kind of mean values as the voltage changes along the ion path in the lens. By letting, for instance, $\Delta b \sim 0.1$ cm, $a \sim 5$ cm, $S \sim 400$ cm and $V_0 \sim 5 \times 10^4$ V one finds $\operatorname{grad}_x V \sim 5$ V/cm. As the voltage needed in the cylinderlens is about 10 kV it is obvious that the ratio L/D had to be large in order to decrease the effects from the durchgriff.

The defocusing could be diminished by shielding for the durchgriff but in that case one got a lens action in the x-axis, which disturbed the focusing. The best conditions have been obtained by incrasing the ratio L/D without shielding. As the limit of the focusing in the vertical direction is set by the cylinder aberration D cannot be made to small; a suitable value of D being $\sim 5\,d$ (d is the diameter of the ion beam). The length of the electrodes had then to be about 40 d in order that the defocusing should be negligible. This is seen in Fig. 7, which shows a recording of Kr^{85} with and without compression of the line for these dimensions of the cylinder lens. The half-widths of these two lines are in fact equal within the experimental errors. The intensity distribution on the y-axes for the two actual lines is given in Fig. 8, which indicates a line-height decrease of about 3.5. The cylinder aberration starts after a line height diminishing of about a factor of 4.5. This could not be reached when these measurements were done because enough voltage was not available. The voltage used in this record was 20 kV for an accelerating voltage of 55 kV.

As most effort with the system described above has been to avoid the durchgriff caused by the high tension needed, it would be suitable to try an arrangement which works with low voltage as for example a deflector. A system consisting of three plates parallel to each other and with the outer two at zero potential and the middle one at a negative voltage has therefore been investigated. By letting the beam pass symmetrically through the deflector, it was possible to decrease the line height to one half. However, it was difficult to avoid an increase of the intensity of the "tails" of the lines by this procedure, which made the system less applicable.

x and y plates

The horizontal deflection—or x-plates are used as stabilizing organ correcting the beam position as controlled by the "pin stabilizer" at the collector house. The plates are situated just behind the accelerating system as is seen in Figs. 2 and 5. The vertical deflection—or y-plates are used to change the vertical position of the mass spectrum at the target which is often necessary. The arrangement is situated at the entrance of the magnet.

Power supplies and stabilizers

All voltages for the ion source and the electrodes are generated in small, oil-insulated units mounted together to a single unit [1]. The primary tension is stabilized for voltage fluctuations and particularly for slow frequency changes by a Sörensen regulator. The aceleration voltage is stabilized to about $5:10^4$, which means a displacement of 0.8 mm of a mass line at the collector.

The magnetic field [1] is produced by two water-cooled coils. For the maximum current of 165 A, a field of 3500 G is reached, which is sufficient for the separation of the heaviest elements. The power is delivered by a 9 kW motor generator. The magnetic field is stabilized by a high speed regulator (ASEA type YRLBE) to about 0.5 % corresponding to a 1.6 mm displacement of a line at the collector.

The rough stabilization of the high tension and the magnetic field must be completed by a fine stabilization. This is done directly on the mass line by a modified "slit stabilization" as described by Thulin [3]. A reference line is focused between two narrow, individually insulated metal strips, which thus receive the same current. If the mass spectrum tends to move, the current symmetry changes and a voltage will be imparted to the x-plates resulting in a compensating deflection on the ion beam. As this type of arrangement has been found to give a satisfactory stabilization, the original test electronic arrangement has now been replaced by a more sensitive one.

Detecting technique and collecting device

For a rough detection, the reference isotope spectrum is observed visually on a fluorescent screen, consisting of a glassplate on which is a layer of zinc-silicate with a small amount of graphite powder. The latter having the property of smoothing out oversensitive parts of the screen. By this arrangement it is not possible to see finer details of the line shape. That must be done by a more sensitive method. One which gives the momentum pictures of the mass lines is the following [6]. By modulation of the accelerating voltage by a 50 c/s sinusoidal signal, the ion beam is swept over a narrow slit at the collector. The signal from a plate behind the slit is fed to the y-plates of an oscilloscope, which thus gives the mass spectrum. However, there are some disadvantages in sweeping the beam. The main one is that it is necessary to break the separation when an observation is made. In the separation of stable isotopes the loss of time for such an observation can often be tolerated, but in the

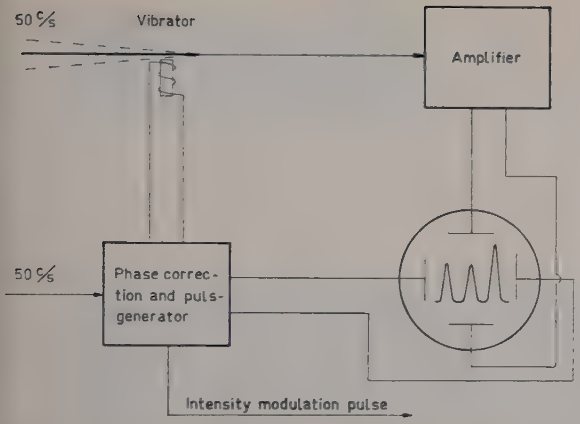
50 c/s
Vibrator
Amplifier
50 c/s
Phase correction and pulsgenerator
Intensity modulation pulse

Fig. 9. Block diagram of the vibrator arrangement.

case of radioactive isotopes with short half-lives it is a great drawback. Further, to get optimal focusing conditions during the separation, a continuous observation of the mass lines is necessary. For that reason it would be better to move the slit rather than the beam, when detecting the masses. An arrangement constructed on this principle has been tried here with some success. The signal of the mass spectrum to the oscilloscope comes from a probe, which sweeps over the fixed beams at the target. The probe is a 0.25 mm steel arm, which is mounted insulated on another steel arm. This is given an oscillating movement by means of a coil, which is excited by a 50 c/s voltage. The length of the arm is then tuned to this frequency to obtain maximal amplitude, about 15 mm. The reason for not using a larger arm and thus a larger vibration amplitude is simply lack of space. However, as the main purpose of the arrangement is focussing control and not mass spectrum identification, the used amplitude is usually sufficient.

As the frequency of the oscillator is the same as that of the main line, irregularities in this will influence the recording. To avoid these a different frequency than 50 c/s should be used. This has been done by Nielsen and Skilbreid [9] in a construction of a vibrator probe that works after the principles given above. The choice of frequency appears, however, to be of less importance.

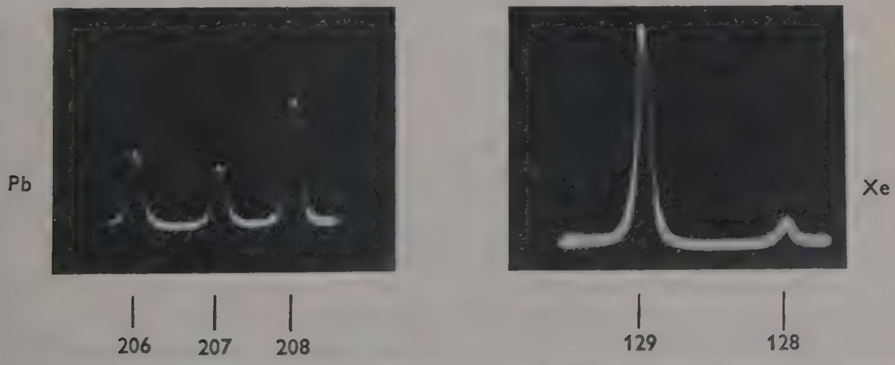

Fig. 10. Oscilloscope pictures of parts of Pb and Xe mass spectrums taken with the mechanical vibrator.

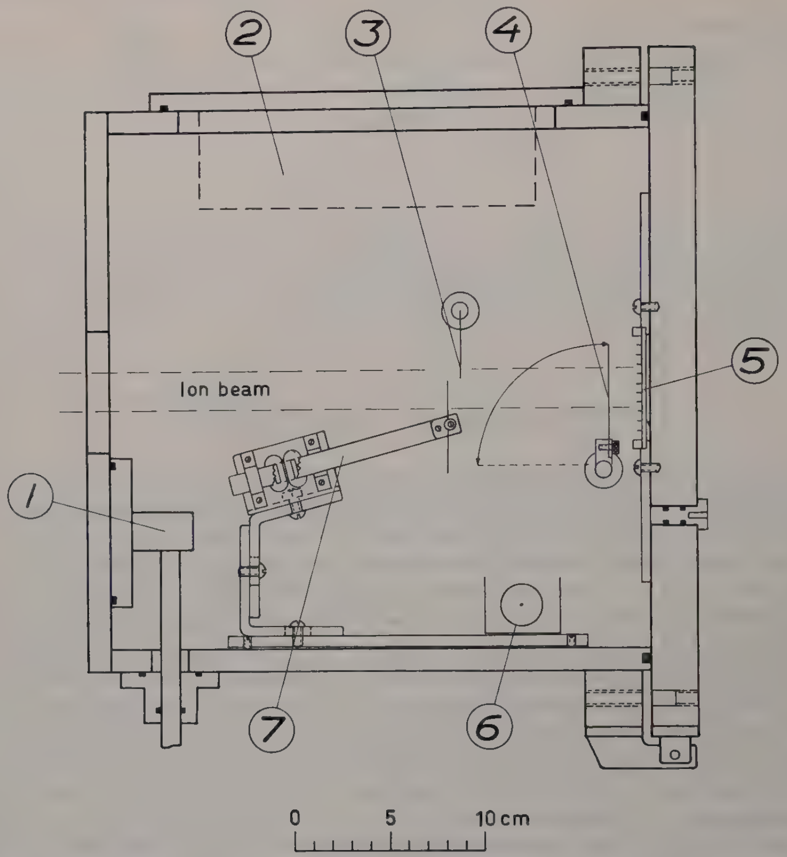

Fig. 11. The collector house. 1. Vacuum valve. 2. Liquid air cooling trap. 3. Stabilizer pins. 4. Collecting plate. 5. Fluorescent screen. 6. GM-counter. 7. Mechanical vibrator.

Examples of mass spectra taken with the mechanical vibrator is given in Fig. 10, which shows parts of the Pb and Xe spectra. The ion current in these cases was about 5 μA. The minimum ion current detectable is of the order of 10^{-8} A.

For detecting and as a control of the radioactive isotopes separated a simple GM-tube is used. Because of the frequent opening of the collector house to take out separated material, which involves changing from air pressure to vacuum, the usual bell type GM-tube is not practical. Instead, a thin walled Al-counter of the type Thyrode 1B85, The Victoreen Inst. Co., is used.

As the amount of material collected is usually very small, the method of direct deposition of the separated ions on metal foils is possible. The foils are fixed on a water-cooled holder, which is insulated from the wall of the vacuum-chamber to make it possible to measure the ion current.

Some characteristics

Below a few characteristics will be given that sum up the present state situation concerning for instance the resolving power, efficiency and the behaviour of the background.

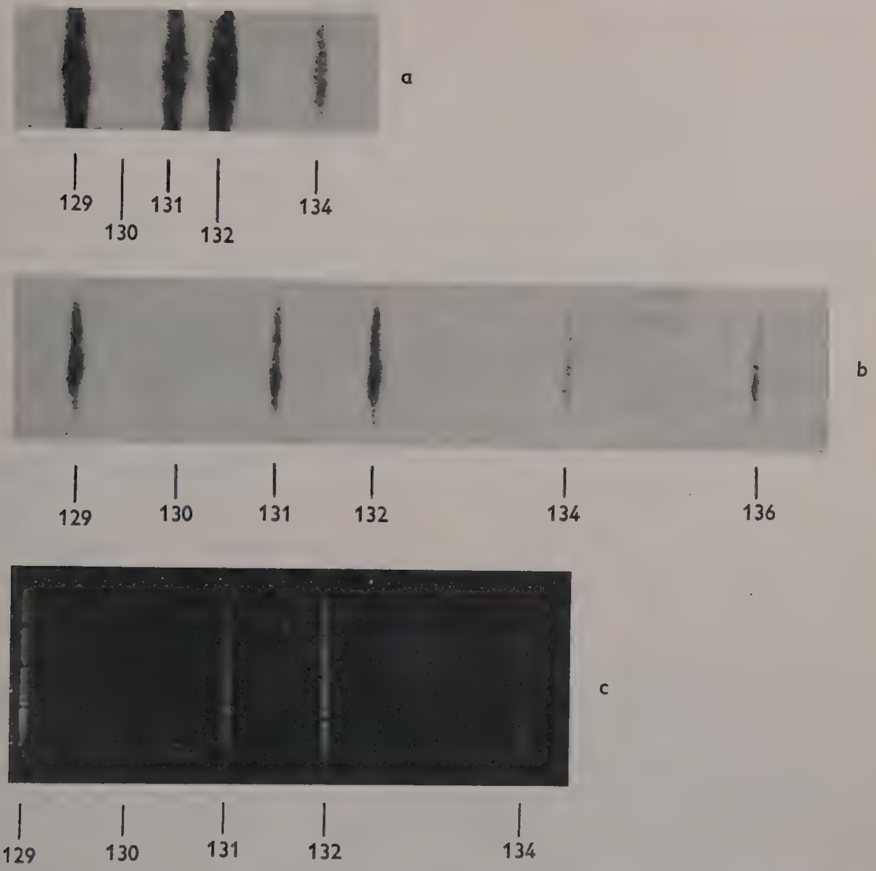

Fig. 12a, b. c. A part of the stable Xe mass spectrum from an older (*a*) and a newer (*b*) record. The photographs show the burn marks made by the isotopes on an Al foil on the target. The pictures are given in natural scale. The separation time was about 30 min. It should be noticed that in *b* the pin stabilizer has been used, which is partly responsible for the smaller line width in this case. (*c*) Photo of the Xe spectrum as seen on the fluorescent screen.

Fig. 12 is an illustration of the improved conditions obtained after the reconstruction. This shows two photographs of targets with a part of the stable Xe-isotopes where the older one is at the top. Xe has here been collected on an Al-foil for about 30 min. and what is seen in Fig. 12 is the mark of burn of the Xe-isotopes. It should be observed that these recordings are integrated pictures so that fluctuations in high tension and magnetic field will contribute to the focusing. At the lines in Fig. 12b, such effects are, however, reduced considerably by the use of the beam stabilizer. One notices also that the distance between two masses has in fact increased more than a factor of 2 by using sector field focusing. This is probably due to that in the last case a larger edge effect from the magnetic field is present. This gives a larger ion path radius, which should influence the dispersion. From the expression (1) one finds an increase of the radius of about 5 %.

As an example of resolving power contra efficiency, Fig. 13 gives a record of Xe.

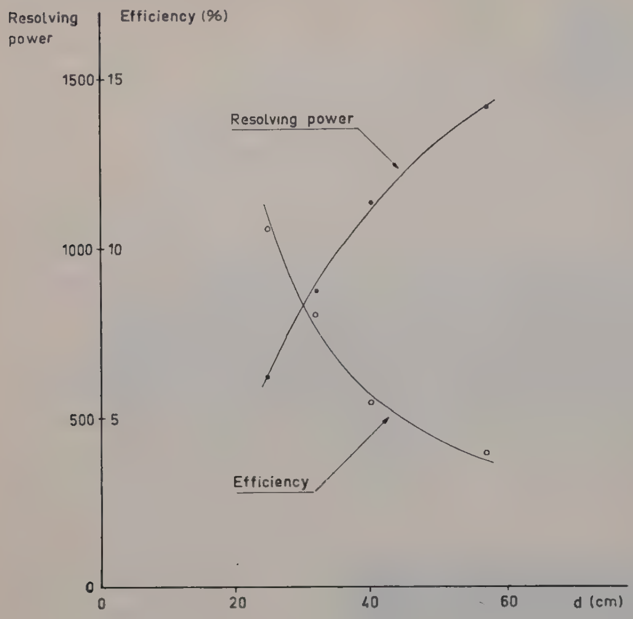

Fig. 13. The resolving power and efficiency for Xe as a function of the distance between the ion source and the accelerating system. The accelerating voltage was 50 kV while the outlet area was 1.5 mm².

The actual values are here measured as function of the distance between the outlet of the ion source and lens system for fixed acceleration tension (50 kV) and outlet area (1.5 mm²). The efficiency is measured from the current reaching the collector and an estimation of the gas consumption, while the resolving power is taken by the vibrating probe. It should be noted that the resolution is here somewhat better than what was obtained in the original measurements with symmetrical sector field focusing. That is due to the fact that in the earlier investigations the optimum focusing plane was not used. This has later been searched for in more detail.

The obtained efficiency for Xe cannot be reproduced to other substances than those easily evaporated as long as only the cathode filament serves as heater in the discharge chamber. It has been possible, for example, to separate Pb in the form of $PbCl_2$ with an overall efficiency of 8 % (measured with the radioactive isotope Pb^{212}) at a resolving power of 600. An overall efficiency here means a collection of both Pb^+ and $PbCl^+$, which occurs in the proportion 60 % and 40 % resp. in the ion beam leaving the ion source. In contrast to this, for example, it has not been possible to separate Bi with better efficiency than 1 %. The charge material was here BiCl, which very easily dissociates to Bi and Cl in the furnace of the ion source. The temperature in the discharge chamber is then too low to hinder condensation of Bi on the walls. However, even with this rather low efficiency, separated activities can be valuable. One actual case that can be mentioned here has to do with two Bi-isotopes with mass numbers 203 and 204. These happen to have about the same half lives (12 h) and as the number of γ-transitions in each isotope is very large, it is difficult to distinguish them, especially when using low resolution as in β–γ-coincidence investigations. Fig. 14 shows two beta spectra taken in connection with such measurements [10]. Fig. 14a is a mixture of the Bi isotopes 203, 204 and a small amount of 205, while 14b gives the β-spectrum of Bi^{204} from a separated sample. From the two peaks A

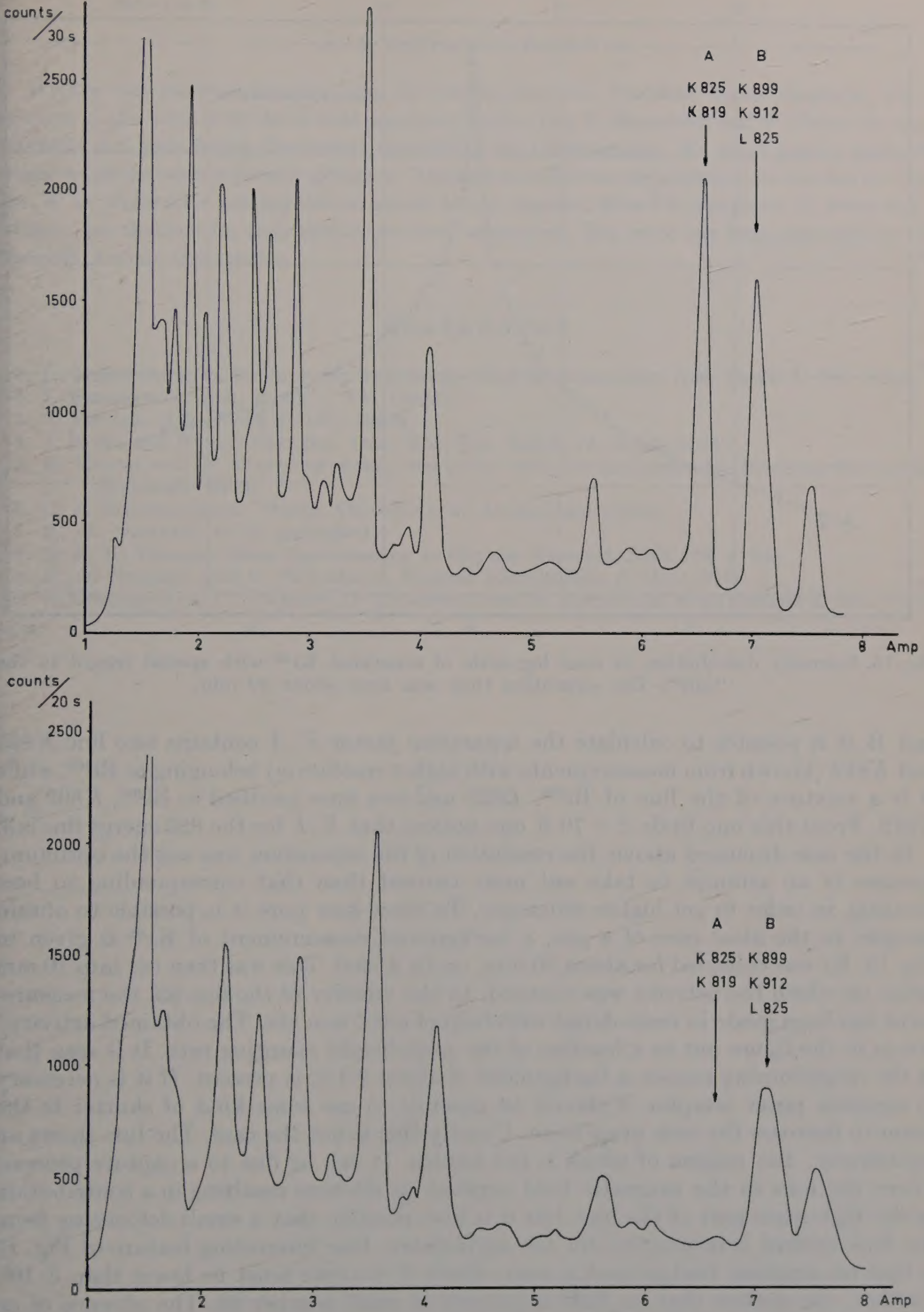

Fig. 14a, b. Conversion electron spectra of two Bi samples. *a*. A mixture of the masses 203, 204 and 205. *b*. Bi^{204} alone after isotope separation.

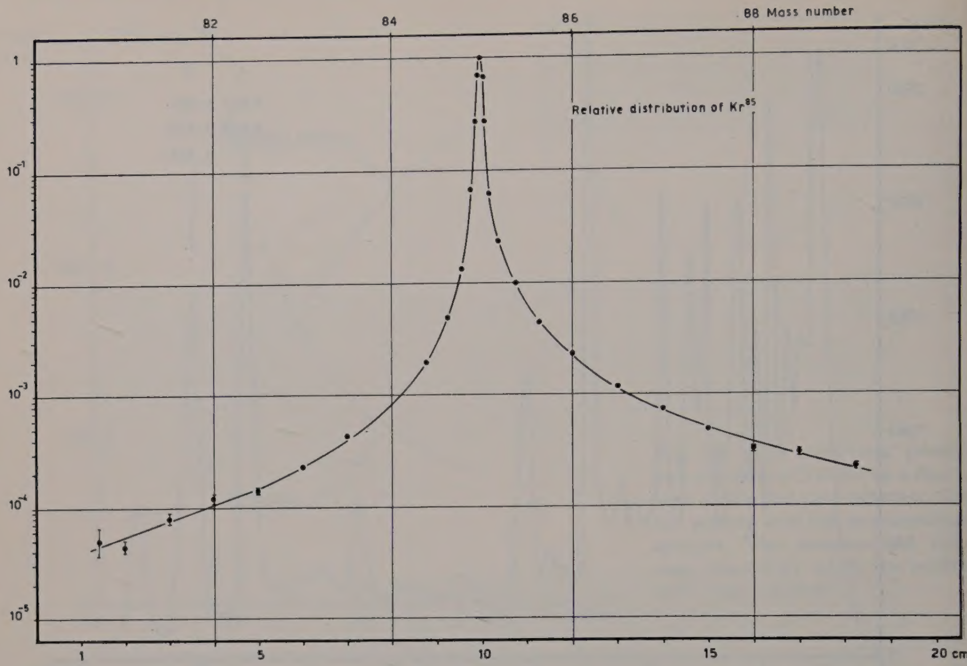

Fig. 15. Intensity distribution in semi log scale of separated Kr^{85} with special regard to the "tails". The separation time was here about 30 min.

and B it is possible to calculate the separation factor S. A contains two line K825 and K819 (known from measurements with higher resolution) belonging to Bi^{203}, while B is a mixture of the line of Bi^{203}, L825 and two lines ascribed to Bi^{204}, K899 and K912. From this one finds $S = 70$ if one notices that K/L for the 825 energy line is 3.

In the case discussed above, the resolution of the separation was not the optimum, because of an attempt to take out more current than that corresponding to best focusing, in order to get higher efficiency. To show how pure it is possible to obtain samples in the ideal case of a gas, a background measurement of Kr^{85} is given in Fig. 15. Kr was collected for about 30 min. on an Al-foil. This was then cut into 10 mm strips on which the activity was counted. In the vicinity of the line 85, the measurement has been made in more detail with help of a 0.2 mm slit. The obtained activity/mm is in the figure put as a fraction of the peak-height counting rate. It is seen that at the neighbouring masses a background of about 0.1 % is present. If it is necessary to separate purer samples, it should be possible to use some kind of shutter in the beam to decrease the tails even more. Usually this is not the case. The line shows an asymmetry, the origion of which is not known. It can be due to a capture process, where the ions in the magnetic field capture an electron resulting in a contribution to the high mass part of the line, but it is also possible that a small defocusing from the lens system is responsible for the asymmetry. One interesting feature of Fig. 15 is that no constant background is seen, which if it exists must be lower than $5:10^5$. Further, one notices that no KrH is present at mass number 86. The absence of an appreciable amount of H in the system is probably due to the use of freon cooled buffles and the proper construction of the discharge chamber.

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